



Fermilab

*Improvements
to
Main Injector RF*

Ralph J. Pasquinelli

2/25/04



Fermilab

Main Injector RF

■ *Multiple modes of operation with same hardware*

- *Slip Stacking*
- *2.5 MHz $p\bar{b}$ acceleration*
- *Five batch operation for NuMI*
- *Fixed target operations SY 120*
- *Coalescing*



Fermilab

Main Injector RF

■ *System Requirements*

- *Beam loading/Feed forward compensation*
- *Maximum voltage for acceleration*
- *Zero volts for 2.5 MHz pbar acceleration*
- *Programmed volts for coalescing*
- *Two frequency operation for Slip Stacking*



Fermilab

Main Injector RF

CUBIC
DEFENSE APPLICATIONS, INC.
A member of the Cubic Corporation family of companies

PRO FORMA INVOICE
(PRICE QUOTATION)

TO: FERMILAB
ATTN: John Reid
P.O.Box
Batavia, IL 60510
(630) 840-4984 jsroid@fnal.gov
FAX:

DATE: 21-Aug-03
NUMBER: Q-3244A

VALIDITY: 30 November 03
EST. SHIP: 180 Days ARO (Subject to Availability)
TERMS: Net-30
FOR: POWER AMPLIFIER

ITEM	QTY	DESCRIPTION	PART NUMBER	UNIT PRICE	EXTENDED PRICE
1.0	40	1kW Solid State Amplifier Module	L161339	\$7,404	\$296,160
1.1	80	1kW Solid State Amplifier Module	L161339	\$5,964	\$477,120

NOTES:
1 Prices are EX WORKS, San Diego, California in US\$. All shipping charges, banking charges, taxes, customs, duties and insurance are to the account of the buyer.
2 The equipment is covered by the standard Cubic 12 month warranty.
3 Cubic standard terms and conditions apply.

Cubic Defense Applications, Inc.
9333 Belvoir Avenue, San Diego, CA 92123
858-505-2717 : Fax 858-505-1593
www.cubic.com

Dawn Ebert
Signature

Figure 9. Amplifier Quote

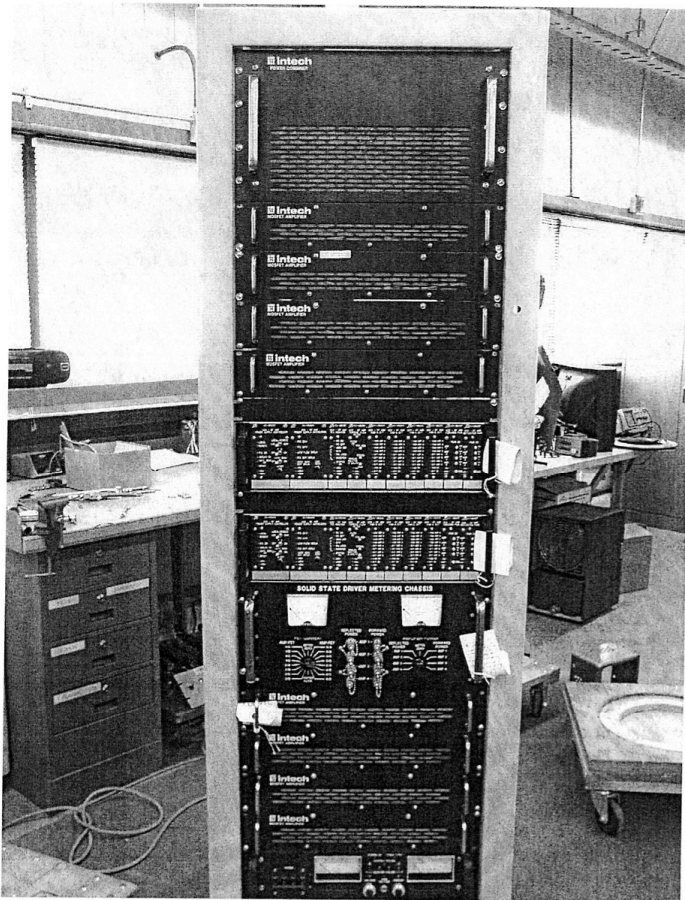
Solid-State Amplifier Quote \$477K for 80-1 KW units

R. J. Pasquinelli



Fermilab

Main Injector RF



*Modified Solid State
Amplifier Relay Rack
Now operational in Station 2*

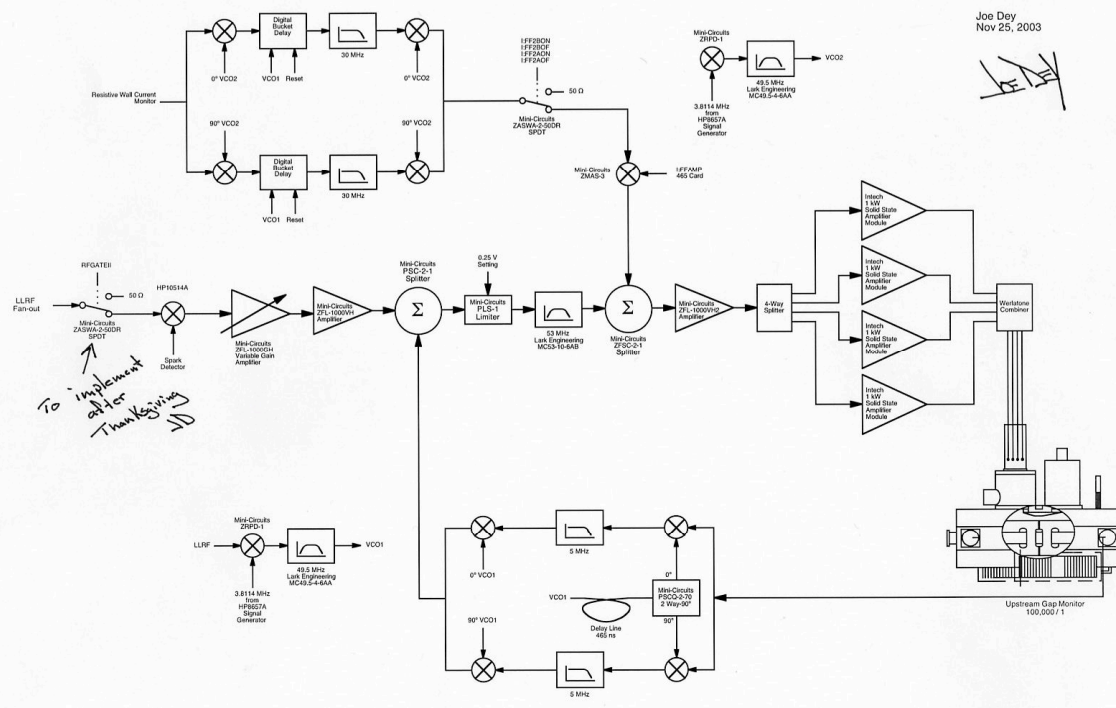
Figure 10. 8 rf modules in standard relay rack with 8 way combiner.

R. J. Pasquinelli



Fermilab

Main Injector RF



49 MHz feedback and feed forward Block Diagram

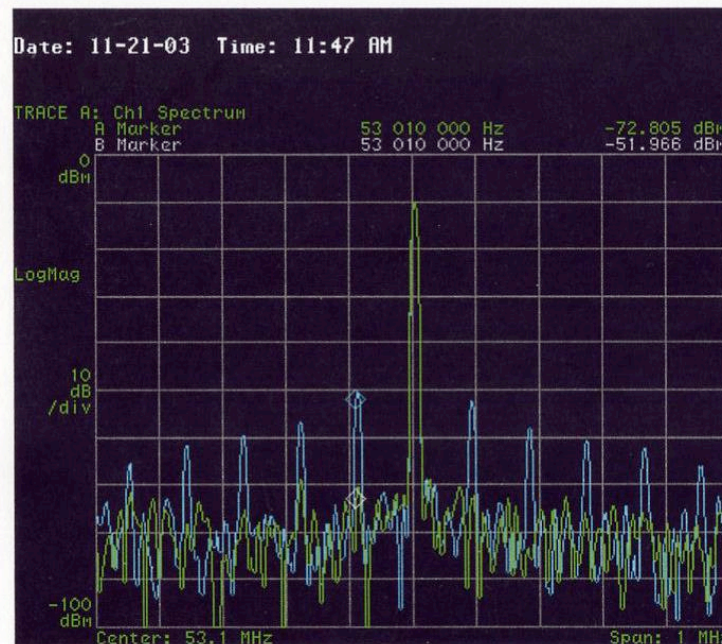
R. J. Pasquinelli



Fermilab

Main Injector RF

*Suppression of revolution harmonics with 49 MHz
feedback/feed forward now operational on all 18 stations*



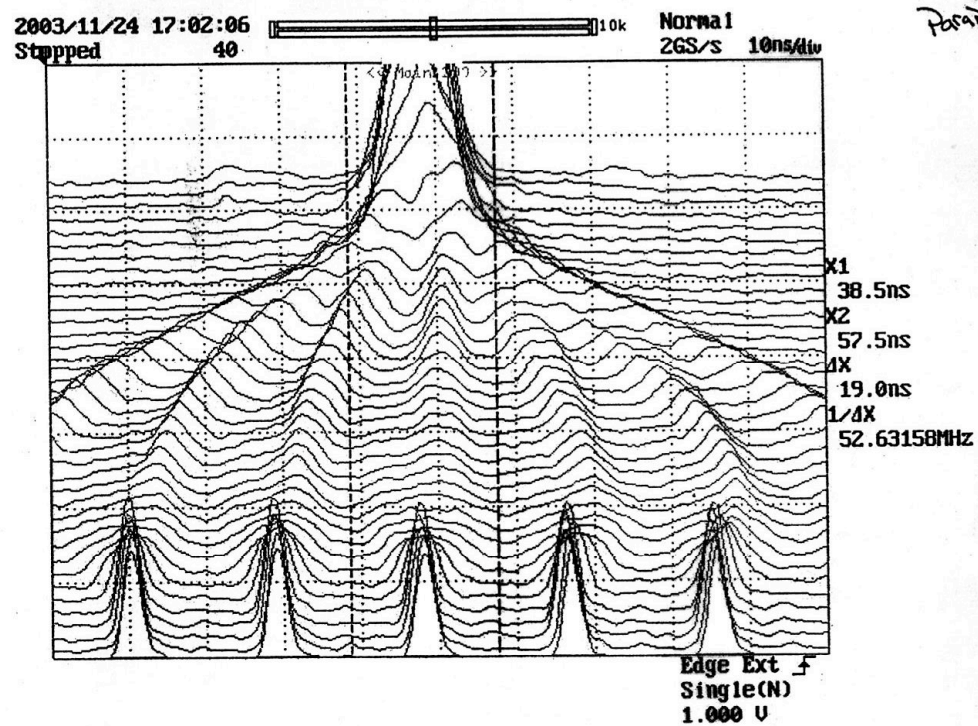
FFUTR
Stacking
#29
0.8s
120 GeV

R. J. Pasquinelli



Fermilab

Main Injector RF



Coalescing with Paraphasing

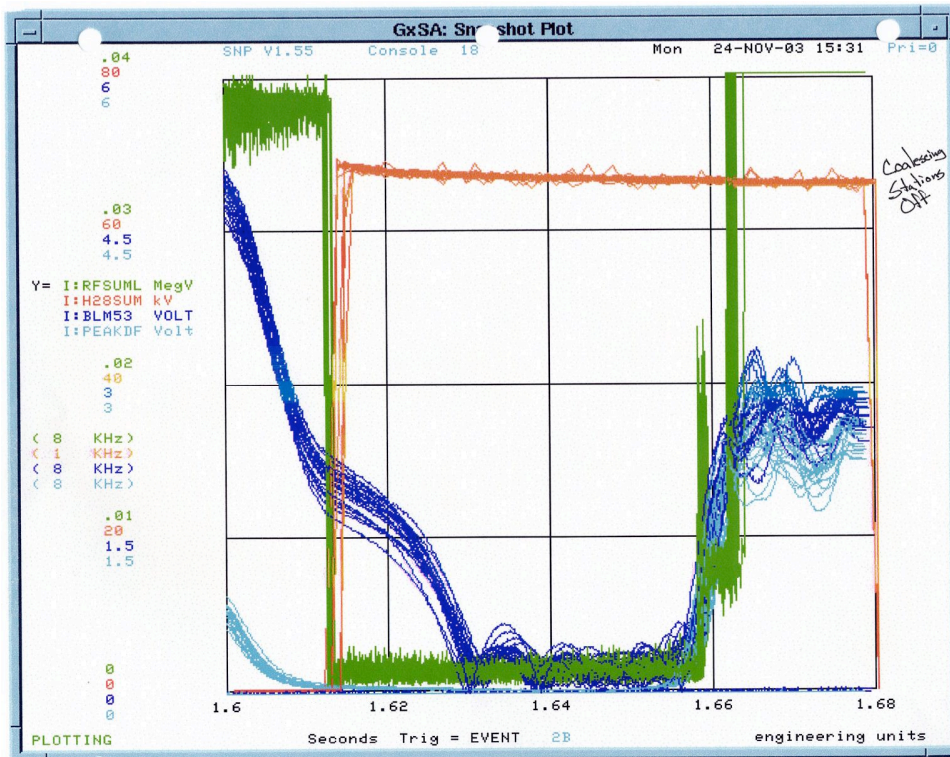
R. J. Pasquinelli



Fermilab

Main Injector RF

Coalescing with Stations Off



*Green 53 MHz Sum
Red 2.5 MHz Sum
Dk Blue Bunch Length*

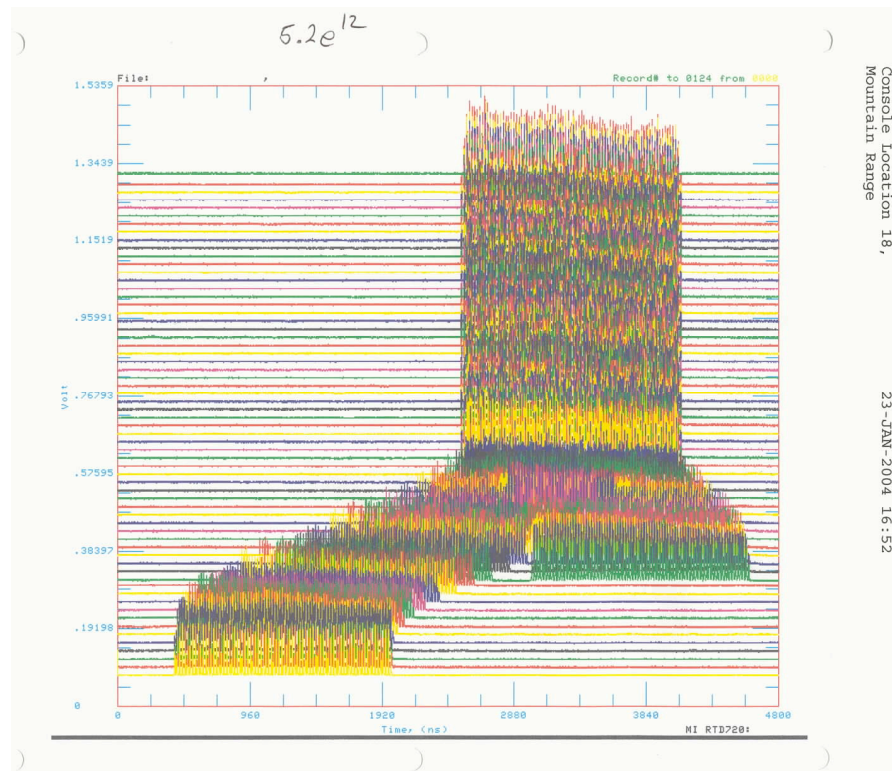
R. J. Pasquinelli



Fermilab

Main Injector RF

Slip Stacking with 5.2×10^{12} protons



R. J. Pasquinelli



High Level RF Model

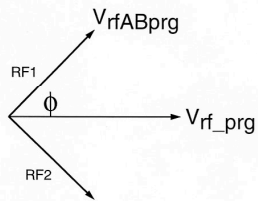




Fermilab

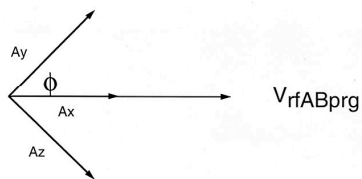
Main Injector RF

Amplitude Control by Vector Angle Modulation



$$V_{rf_prg} = 2 \times V_{rfABprg} \times \cos(\phi_{rf2} - \phi_{rf1})$$

Medium Level RF (MLRF) Vector Diagram



$$V_{rfABprg} = A_x + (A_y + A_z) \cdot \cos(\phi_{Ay} - \phi_{Ax})$$

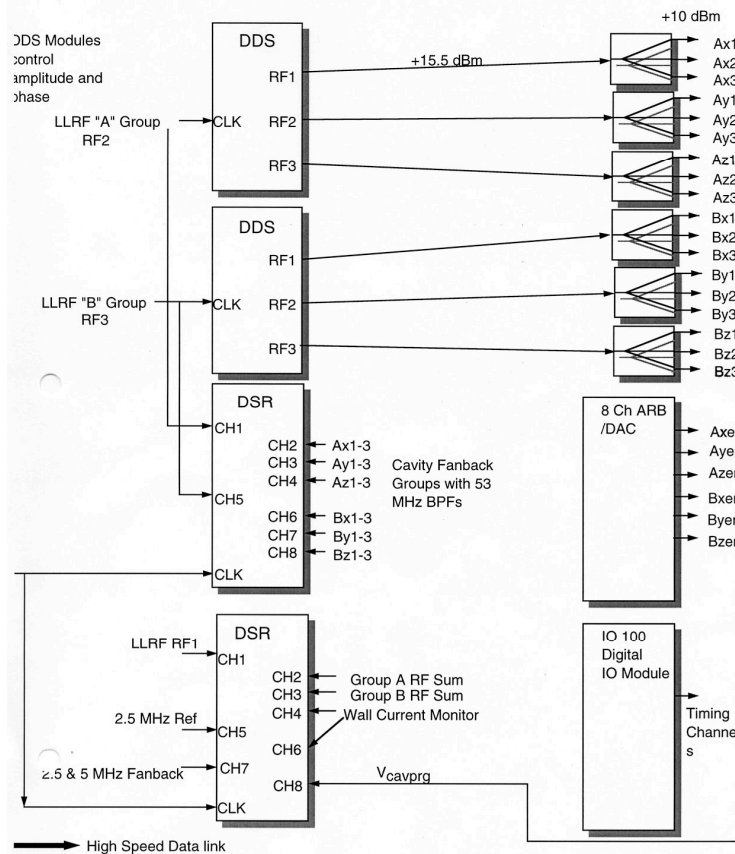
R. J. Pasquinelli



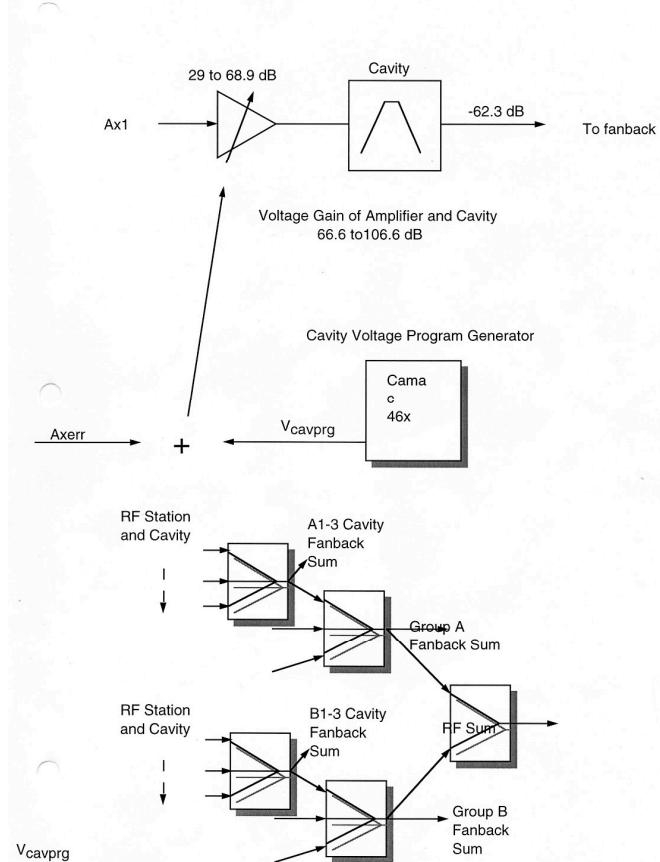
Fermilab

Main Injector RF

Middle Level RF Vector Amplitude Control H588



High Level RF Vector Amplitude Control H588



R. J. Pasquinelli



Fermilab

Main Injector RF

■ *Advantages of this Topology*

- *There are no “special” stations that will stop operation on a single point failure*
- *Vector control may rely more on phase and less on amplitude as any vector may be created without 180 degree angles between vectors. For example, three equal amplitude vectors at 120 degrees sum to zero volts. Any error voltage may be nulled by changing the angle of two of the vectors.*
- *This configuration will allow all the stations to be on at some reasonable level during processes like slip stacking. The PA tube may then be biased to a lower DC current, greatly reducing power consumption while maintaining small signal gain and linearity.*
- *Symmetry in the station grouping is conceptually cleaner and makes the hardware and software design cleaner as well.*



Fermilab

Main Injector RF

- *Project start 11/1/03*
- *Vector controller design topology defined 1/1/04*
- *All HLRF hardware is on order, LLRF hardware in house*
- *Hardware and software for vector controller assembled, including new VXI and fanback box 6/1/04*
- *Installation of LL hardware 7/1/04*
- *Staged installation of HL hardware 4/04-7/04*
- *Testing of system with/without beam 7/15/04*
- *Testing of slip stacking with beam before summer 04 shutdown*
- *Testing of 2.5 MHz acceleration of pbars before 04 shutdown*